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Exploring Homeland Security Applications for Unmanned Autonomous Systems at Maritime Ports

27 MAY 2020

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From: Ben Rohrbaugh, Lantern Unmanned Autonomous Systems, LLC (Lantern UAS)

Date: May 4, 2020

Subject: Final report on Phase 1 of research project - *Exploring Homeland Security Applications for Unmanned Autonomous Systems at Maritime Ports*

This memorandum provides an overview of the work that was done for Phase 1 of the project *Exploring Homeland Security Applications for Unmanned Autonomous Systems at Maritime Ports*, with testing results, an overview of the system that was developed, and the detailed feedback we received from CBP operators about capability gaps that could be met by drone-based solutions.

Our testing focused on the viability of radiation detection from a drone-based system, the ability of drones to capture detailed visual information about container surfaces and particularly door and seals, and the possibility of using thermal imaging to identify human smuggling and trafficking. We also developed plans test LIDAR, use neutron detection, to develop radiation heat mapping, and to test drone-based solutions to the other capability gaps identified by CBP. Per guidance we received on April 6, 2020, the systems we have developed to this point will not be tested further and the additional research identified will not be pursued. There does not appear to be a process currently to transition the work that has been done to operators.

Summary

1. Lantern UAS was able to successfully complete the approved workplan on or ahead of schedule, including establishing a fully operational controlled test environment, determining and obtaining commercially available drones and sensors that would meet testing requirements, and developing specialized software for these applications.
2. Testing results exceeded our expectations for the capabilities of drone-based systems to detect radiation and the system has consistently been able to detect very small radiation sources through container and vehicle walls. Testing and interactions with CBP indicate that this technology has the potential to be successfully transitioned to DHS operators.
3. Once the initial testing had demonstrated the systems capability, Lantern UAS advanced our radiation detection application to the point where results can be displayed visually on the drone controls in real time and we are finalizing the software to display possible alerts in heat map form overlayed on the drone camera feed.
4. We also met with CBP leadership in Washington, DC and the Houston Field Office leadership visited our testing location in February, 2020, and provided detailed feedback on promising aerial drone applications for cargo security.
5. Lantern UAS strongly believes the research in these very promising areas should be continued and that the systems developed to this point should be tested further. We outlined our concerns about the apparent decision to abandon this research in an email sent by David Hansell on April 9, 2020.

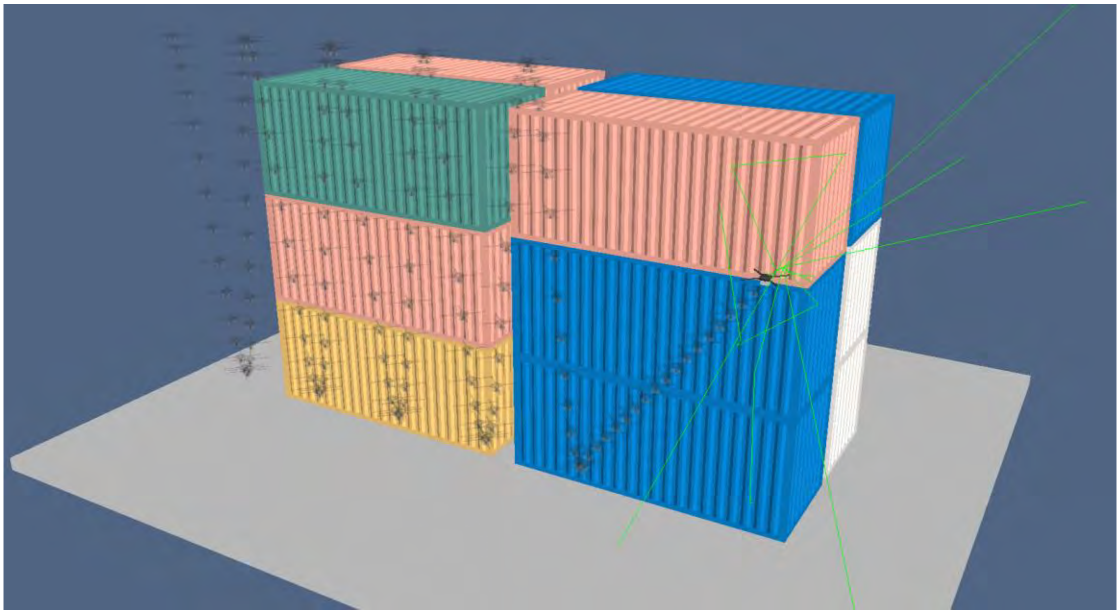
Overview of research results and work done during Phase 1

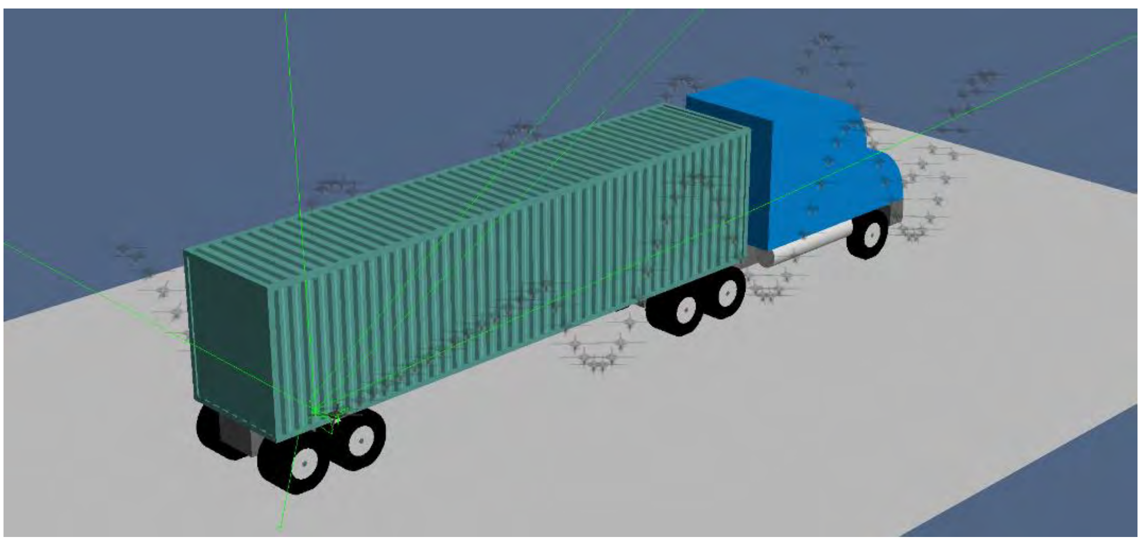
Establishing a controlled testing environment

Lantern UAS was able to establish a controlled testing environment at the University of Houston Technology Bridge location, which provides an excellent industrial testing setting for testing with nearby warehouses, rail lines, oil and gas testing equipment, and vehicles. Lantern UAS arranged three used 40-foot shipping containers with a stack of two and a third container along the side, which provides opportunities to test a variety of different scenarios. 40-foot containers are the most common size for seaborne shipping. We particularly want to extend our thanks to the BTI team for their essential support in finding the testing location and obtaining the necessary agreements and approvals to begin testing ahead of schedule. Working in coordination with the Radiation Safety Officer for the University of Houston we have been able to establish a secure storage location for the radiation test sources that allows us to place the sources at different locations within the containers and vehicles for testing. Lantern UAS also obtained a Wide Area Airspace Authorization from the FAA in 2019 for fights throughout the University of Houston area at up to 200 feet of altitude, which we were able to obtain expeditiously due to our Chief Operating Officer's extensive experience working with the FAA on regulatory approvals to fly unmanned systems in sensitive Images of the controlled testing location are below:

Developing an initial system for radiation detection

Lantern UAS conducted extensive simulations using a framework we developed using Geant4 software to determine a viable system for radiation detection on an aerial drone using commercially available components. Here are several examples of the scenarios for which we have developed simulations, one showing a drone following a double sinusoidal path along a stack of containers before detecting a source and moving to gather more information, and another demonstrating a similar search of a truck. In each image the green lines indicate detectable particles from the source:





The commercially available components of the system that Lantern UAS determined should be initially tested are:

Item	Qty	Notes
Kromek SIGMA50 detector	1	315 grams, Resolution (%@Cs137) <7.2
Raspberry PI with data acquisition	1	
Drone	2	DJI M210 for carrying the radiation system, Mavic for testing thermal imaging capabilities
Router with wi-fi internet	1	Data is initially transmitted from Rasperry PI to laptop over wifi network
Linux laptop with data analysis tools	1	
Calibration sources 1 μCi	3	^{57}Co, ^{137}Cs, ^{60}Co (122,662,173,1332 keV)
Efficiency Study sources (10 μCi)	3	^{57}Co, ^{137}Cs, ^{22}Na
Container sources (10μCi)	5	^{137}Cs

We traveled to Houston in September and assembled the system and conducted detector efficiency measurements with test sources for a half hour each:

Sources used in efficiency measurements

Source	^{57}Co	^{22}Na	^{137}Cs
Activity (μCi)	10	10	10
Data Collection time (min)	30	30	30

We identified 33 "bins", or KeV peaks that allow us to quickly identify likely isotopes. The measured data counts were integrated within corresponding energy bins and corrected for live time. The background was subtracted from the data to determine the signal count rates. We measured the level of background radiation and also did initial stationary tests with the system adjacent to the container wall and not flying. The information gathered on this trip allowed us to develop the detection algorithm that was tested the following month.

Here is an example of the measured background radiation for the Cs137 bin that we collected on this trip, which allowed us to determine the appropriate threshold for an alarm on subsequent tests.

Here is an image of the full system in flight, with the detector visible on the near leg and the Raspberry Pi on the far side:

October testing results – Successful detection

The October testing session was the first time we used our detection algorithm with detector data gathered in flight. We used five 10µCi Cs137 sources placed on the inside of a container halfway up the wall for our initial testing. For this testing, information was collected from each flight and then subsequently processed on the laptop after the testing had been completed. We were able to review the results shortly after flying but not in real time.

The algorithm searches for the peaks, finds peak positions and integrate total counts within the width of the peak. The background counts are averaged and subtracted from total counts. The confidence (or signal significance) is calculated and compared to the detection threshold. The value of 5.2 counts per second was found from multiple source and background runs available up to date and used as a detection threshold value.

We did tests where the drone traveled along the side of the container, over the top of the container, and over a car with the radiation source in the trunk. The drone was traveling at a speed of about one meter per second in each of the tests we conducted. The results for the following scenarios are shown below:

1. Drone flying 1 m/s about 0.8 meters aside from the container wall (about 1m from the source)
2. Drone flying 1 m/s about 0.5-1m above the container top
3. Drone flying 1 m/s above the car from back to front
4. Drone flying 1 m/s across the car from door to door

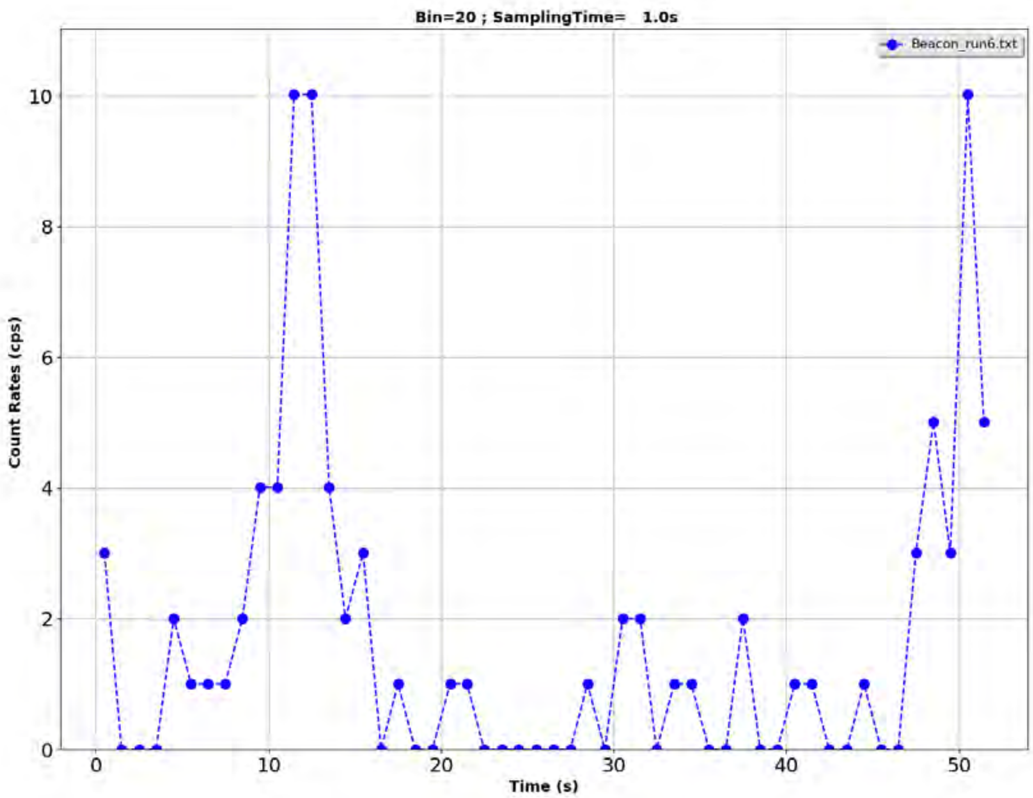


Figure 1: Count rates as a function of time in ^{137}Cs bin for scenario with drone flying 1 m/s about 0.8 aside from the container wall, the drone passes the container twice in this test (about 1m from the source)

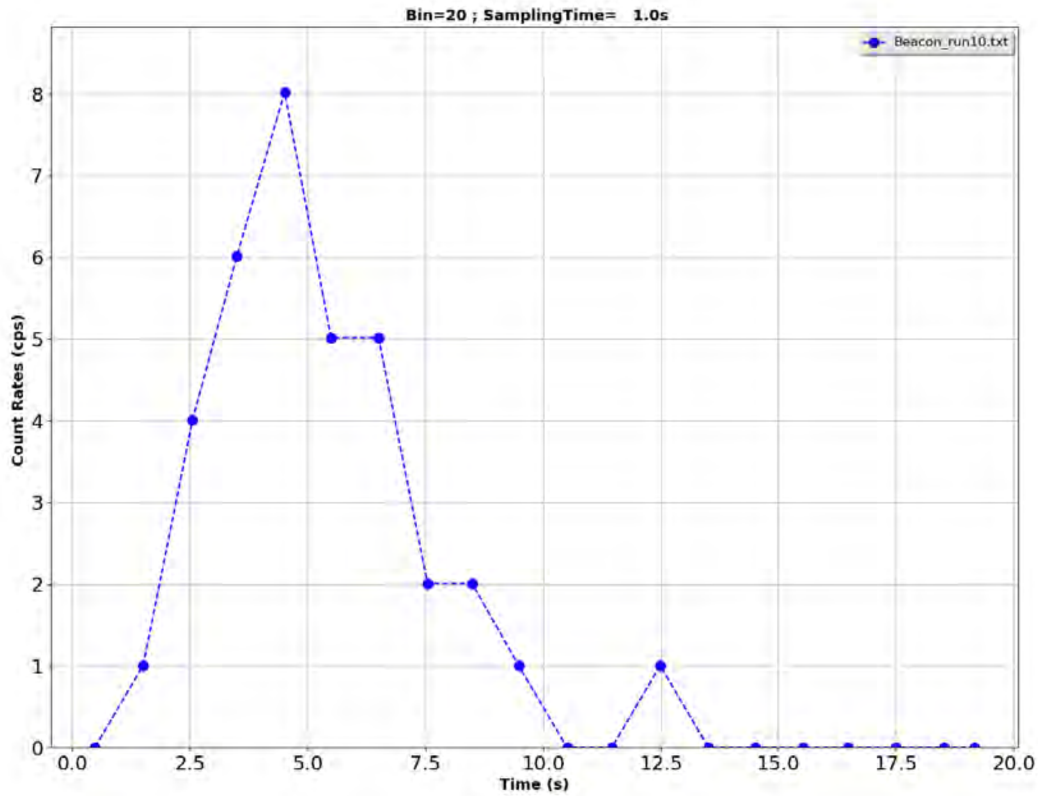


Figure 2: Count rates as a function of time in ^{137}Cs bin for scenario with drone flying 1 m/s about 0.8 aside from the container wall (about 1m from the source)

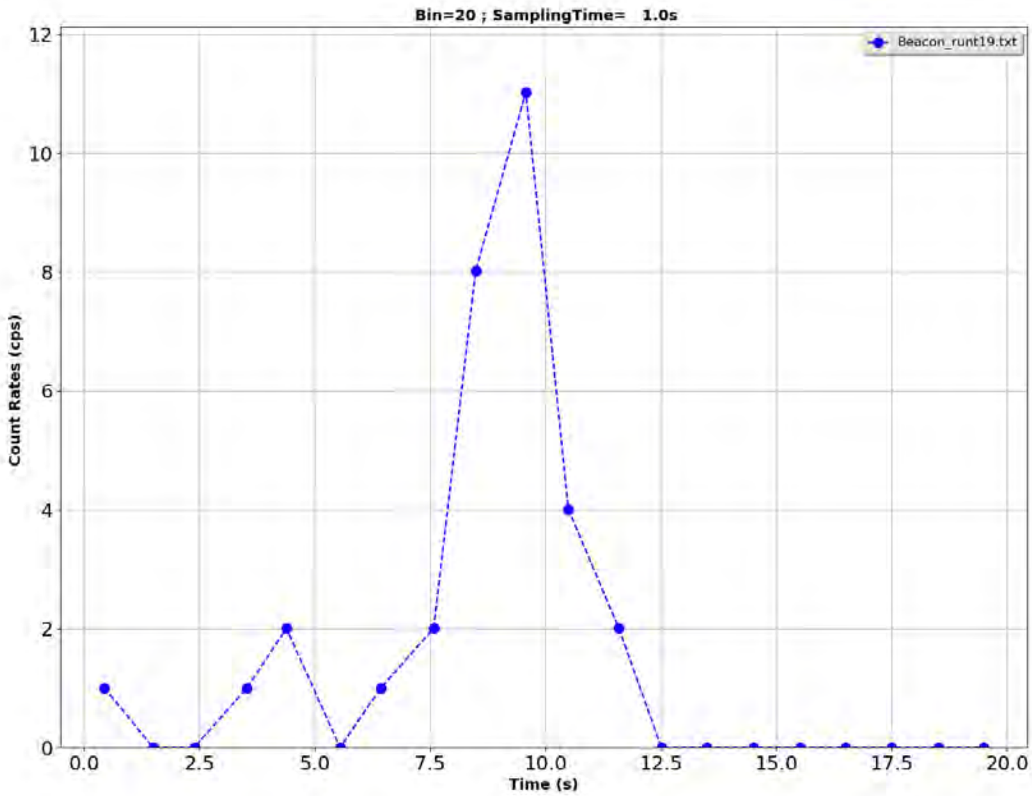


Figure 3: Count rates as a function of time in ^{137}Cs bin for scenario with the drone flying 1 m/s about 0.5-1m above from the container top

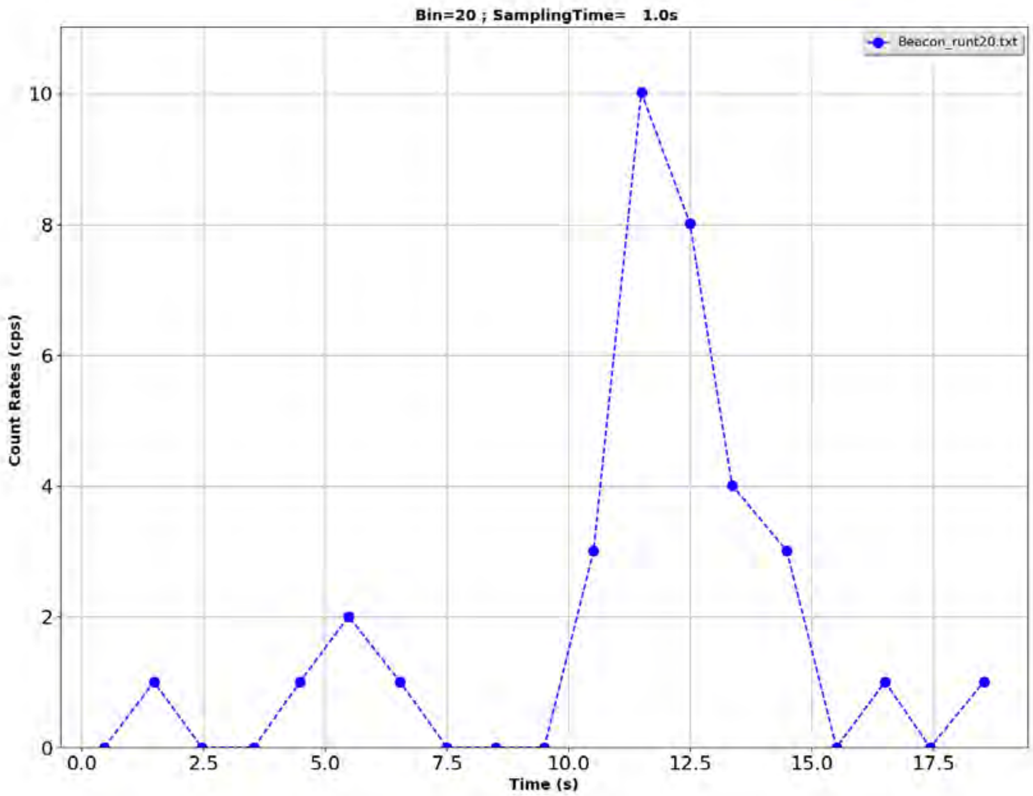


Figure 4: Count rates as a function of time in ^{137}Cs bin for scenario with the drone flying 1 m/s about 0.5-1m above from the container top

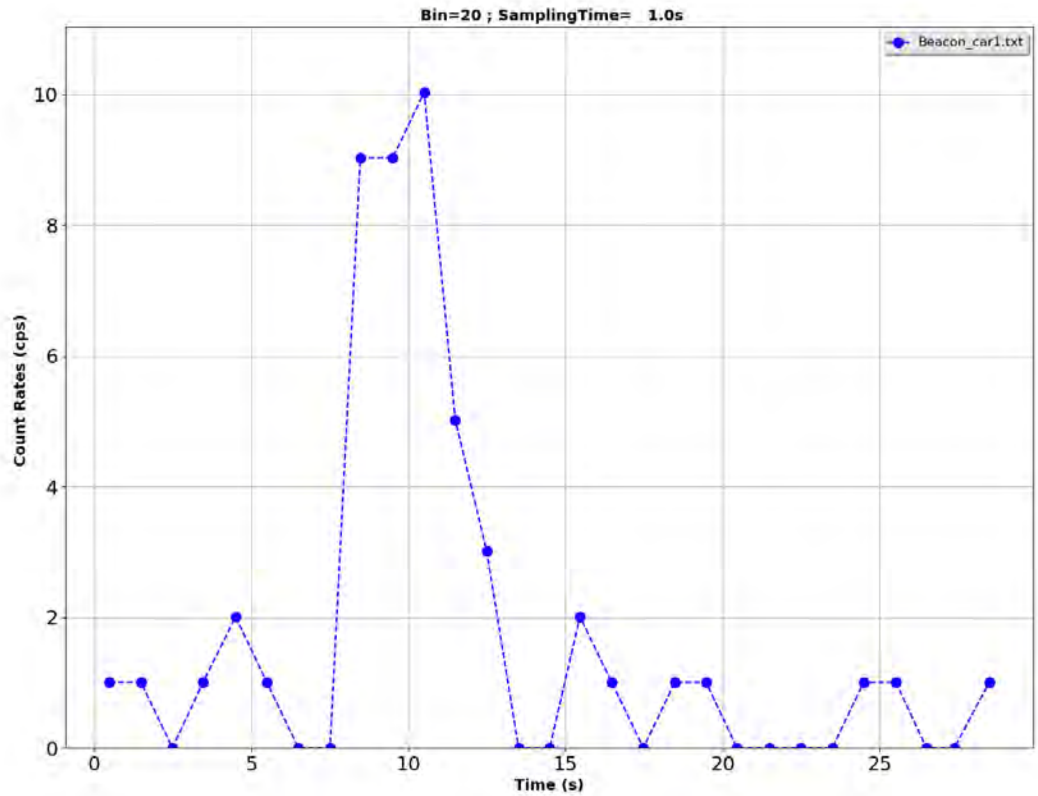


Figure 5: Count rates as a function of time in ^{137}Cs bin for scenario with the drone flying 1 m/s above and along the car

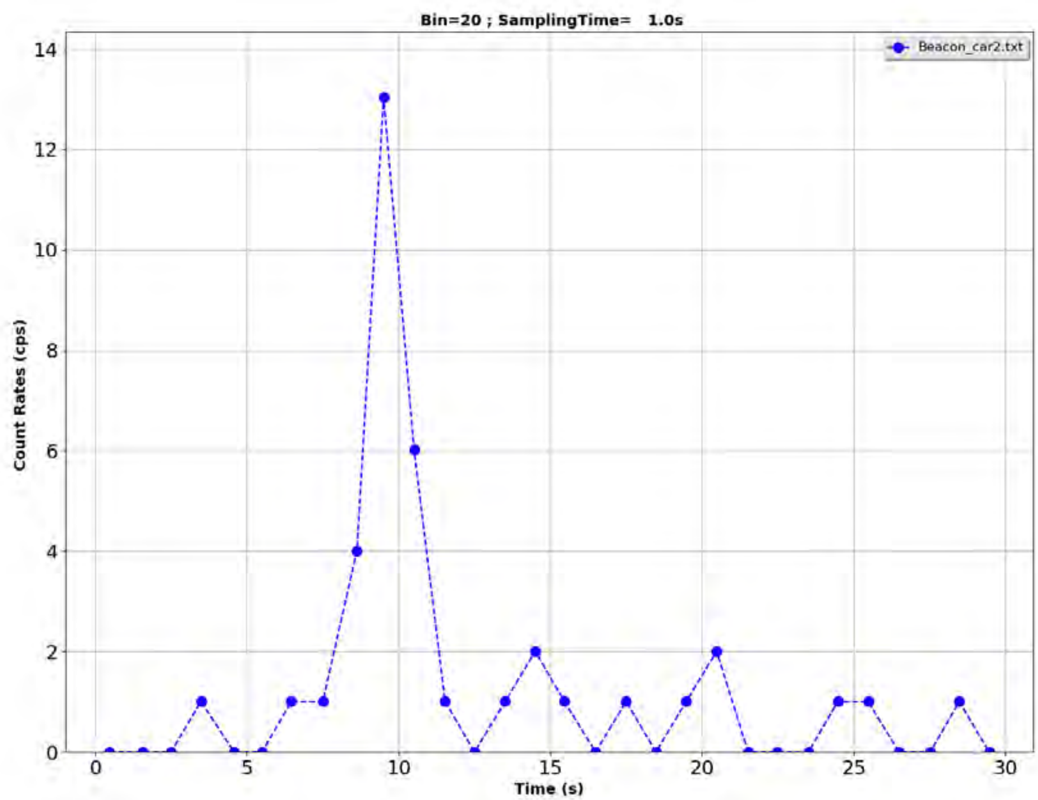


Figure 6: Count rates as a function of time in ^{137}Cs bin for scenario with the drone flying 1 m/s above and along the car

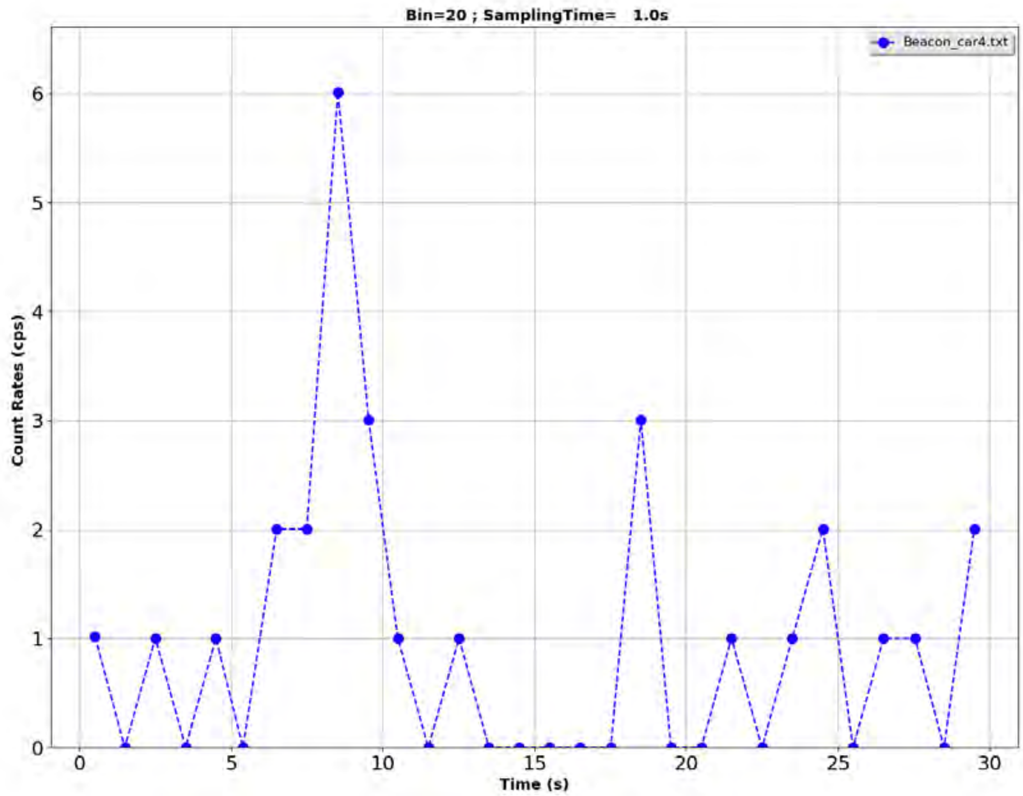


Figure 7: Count rates as a function of time in ^{137}Cs bin for scenario with the drone flying 1 m/s above and across the car

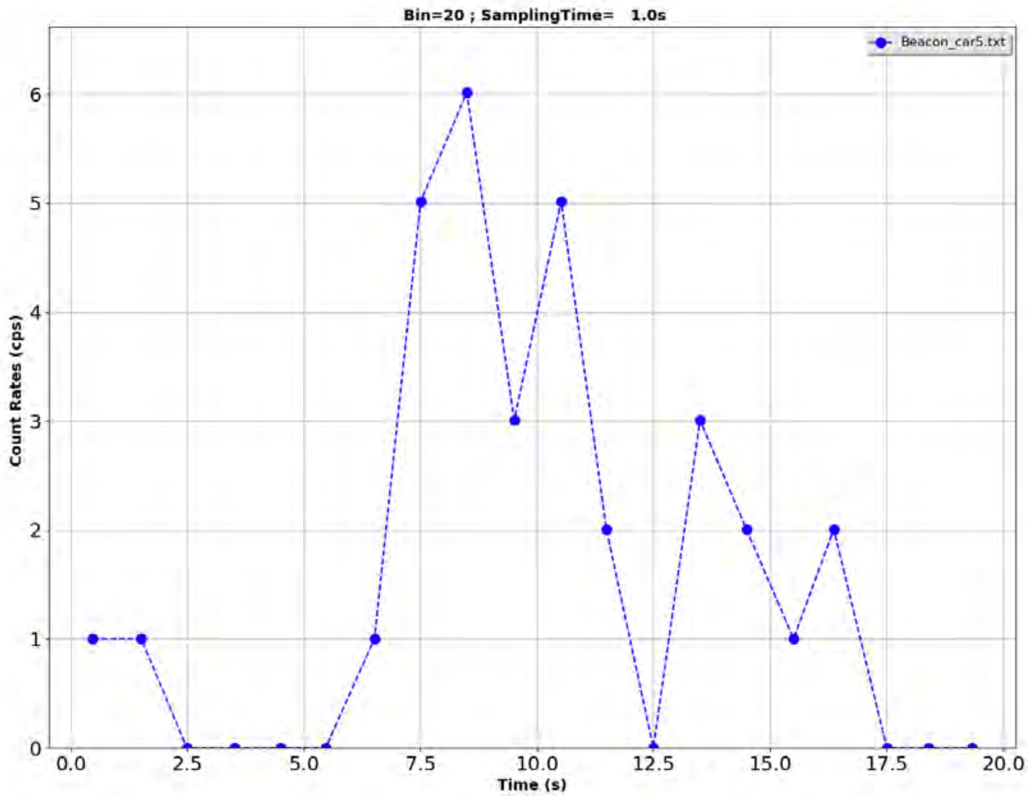


Figure 8: Count rates as a function of time in ^{137}Cs bin for scenario with the drone flying 1 m/s above and across the car

These results demonstrated that the 50µCi Cs137 source was consistently detectable by this system through the wall of the container, the roof of the container, and the car. The results for the drone traveling across the car sideways were less promising due to the larger possible distances between the system and the source, for example a drone flying sideways over the hood of a car might not detect a source in the trunk.

December testing results – Successful source detection and real time results

Subsequent to our September testing session, Lantern UAS developed a software program that processes the results of the runs in real time on a graphical user interface operated on the laptop. This was our first testing date where we were able to see results in real time, with the data to be processed immediately after the drone flight. The results for radiation detection were again quite promising, as is demonstrated below. We conducted a larger variety of tests, shifting the location of the source multiple times, moving it further back from the container wall, and testing whether we could detect the source across two containers (which was unsuccessful).

We also conducted a series of tests with a thermal imaging camera (using a FLIR Lepton thermal microcamera) to determine whether it was possible to identify indications that a person is inside of the container. We had not conducted these tests earlier in the grant period because the summer conditions at the Houston test site meant that the sides of the containers were generally extremely hot. The tests we conducted indicated that our thermal imaging cameras were not able to identify the presence of a person within a container even when the temperature was well below that of a human body.

The tests did demonstrate, however, how quickly aerial drones can be used to gather detailed surface imagery of containers that can either be examined in real time or stored for further analysis, particularly anomaly detection using advanced analytics.

Examples of high resolution images and thermal images collected by the drones:

The radiation detection flights we conducted and the results are below:

Table 1: Runs collected on 12/11/2019

Run#	Run Description
run1	side scan, source close to the container wall in the center
run2	side scan, source close to the container wall in the center
run3	top scan, source close to the container wall in the center
run4	top scan, source close to the container wall in the center
run5	going forward and back, source is in the middle (about a meter and a half back from the container all)
run6	all the way around
run7	regular scan on the side
run8	regular scan on the side.
run9	regular scan, source moved to the end of the container, not detected
run10	regular scan, source moved to the end of the container, detected
run11	50 second scan- 20 seconds forward, 20 seconds back, 10 seconds close, source is at the end, detected
run12	source is in the center of the container - drone is on the other side (1 container separation) 30 seconds of data
run13	source is in the center - drone is on the side 30 seconds of data

Figure 9 -- Figure 15 show the GUI screen with real time results for most of the runs listed in Table 1. In all these runs the source was detected except for the Run12 that had the detector and the source separated by another container.

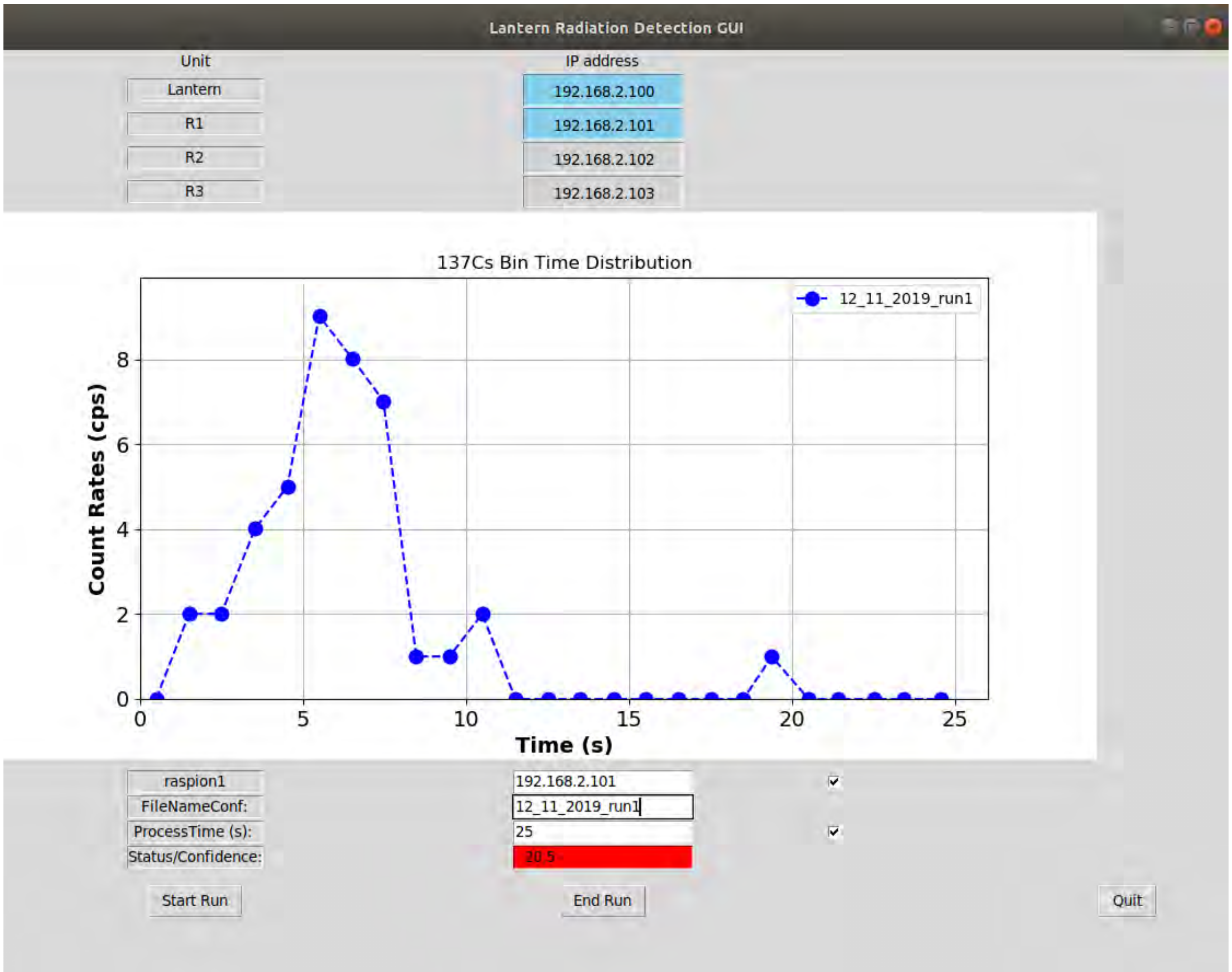


Figure 9: GUI Screen reflects source detection for the Run1 data

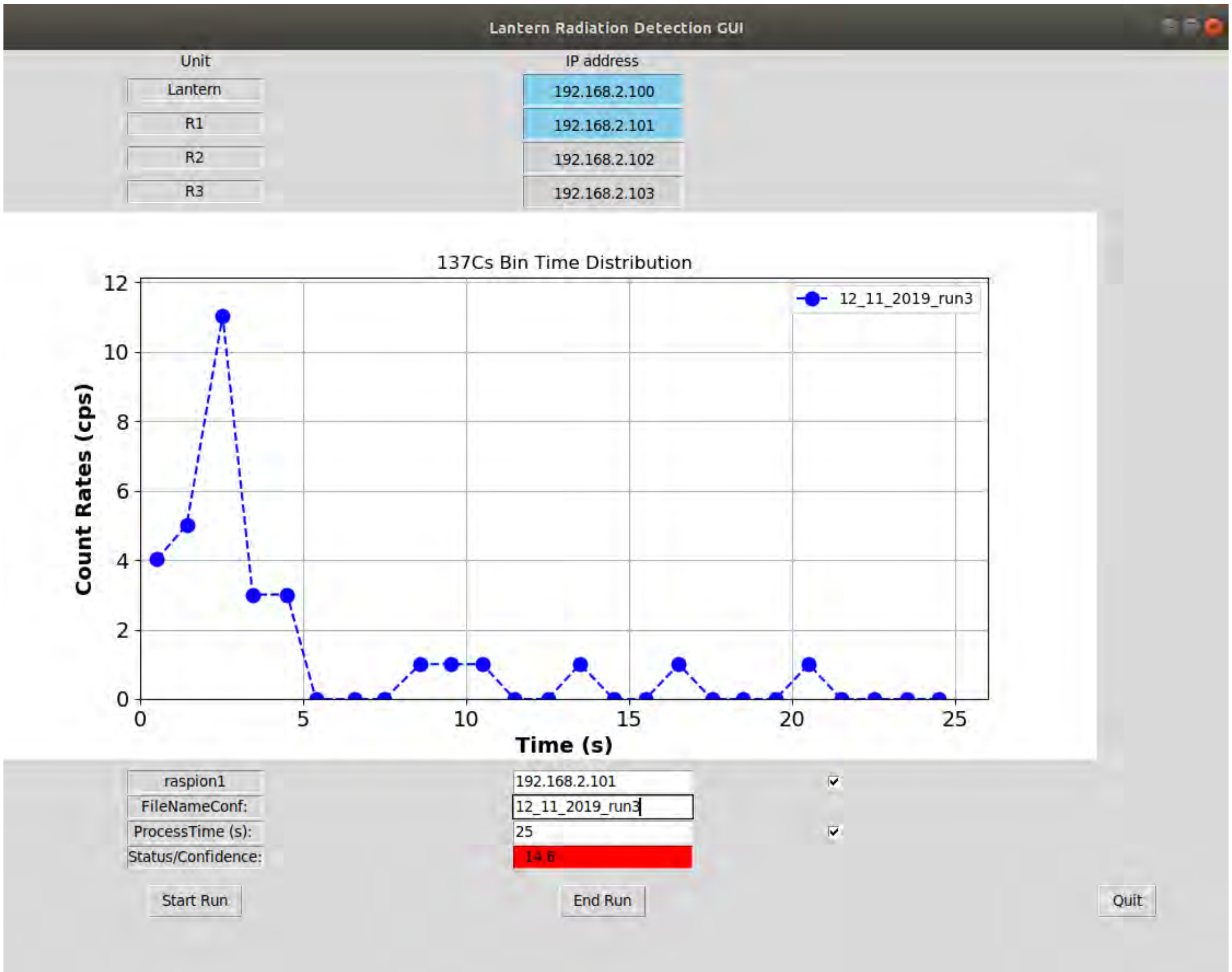


Figure 10: GUI Screen reflects source detection for the Run3 data

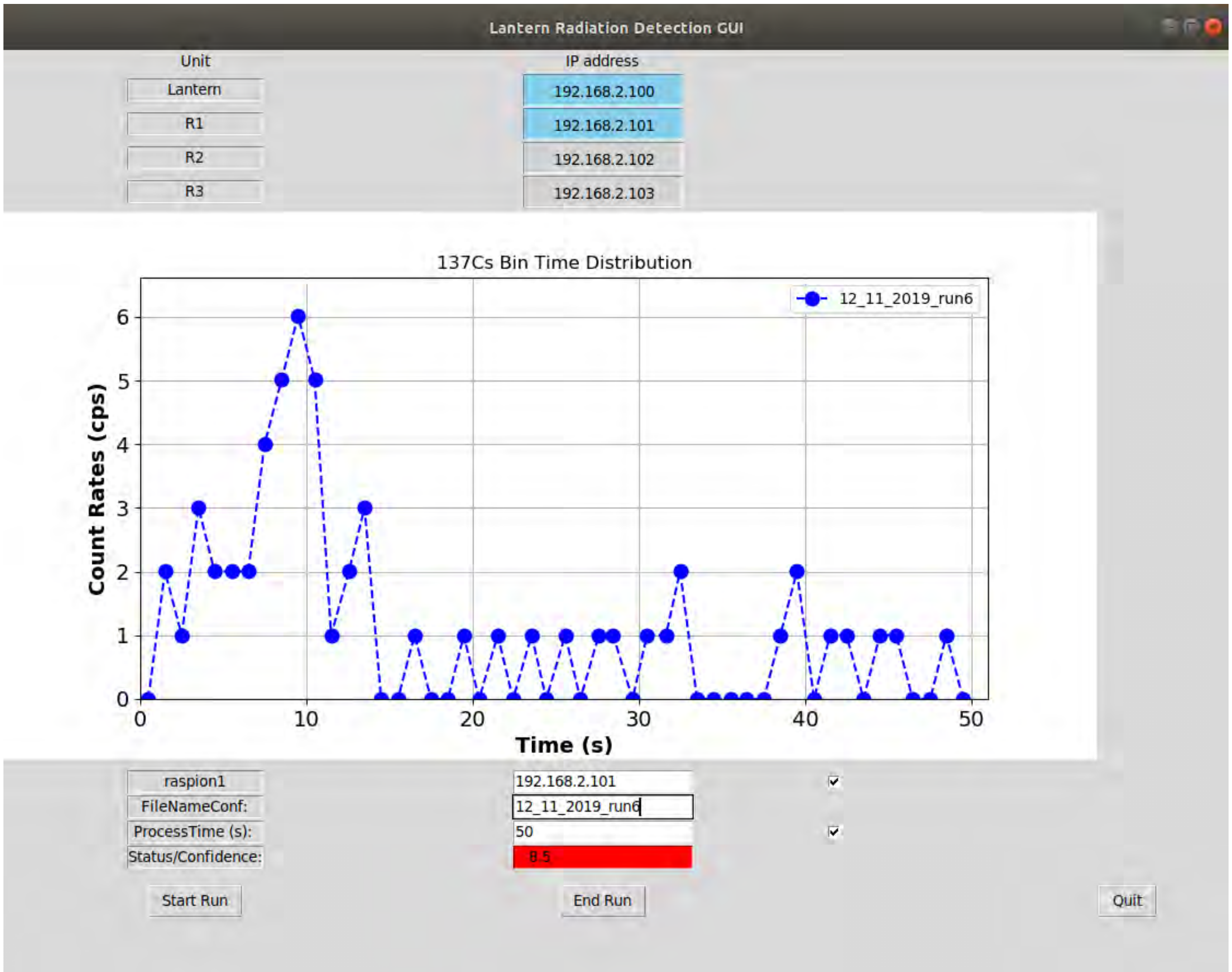


Figure 11: GUI Screen reflects source detection for the Run6 data

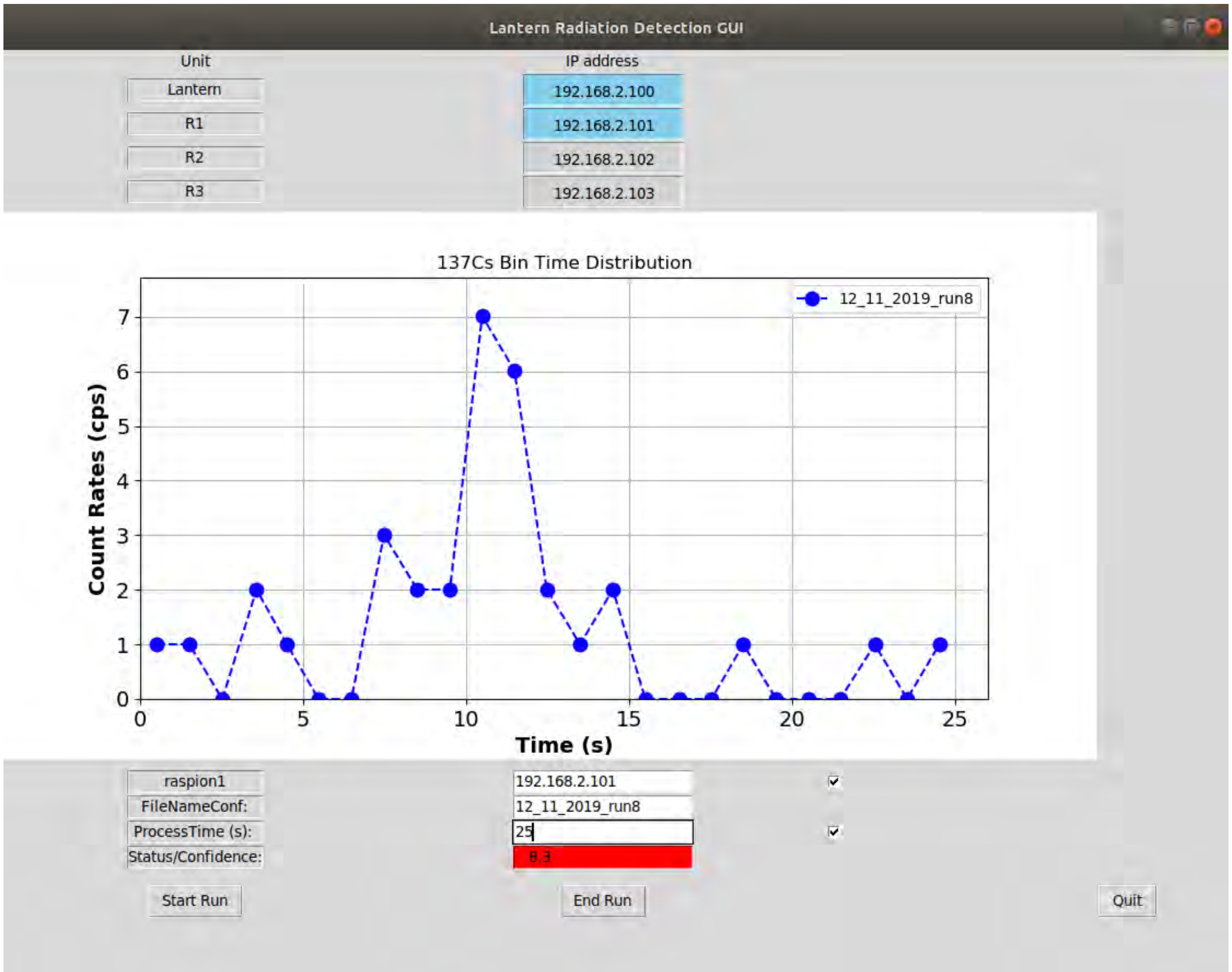


Figure 12: GUI Screen reflects source detection for the Run8 data

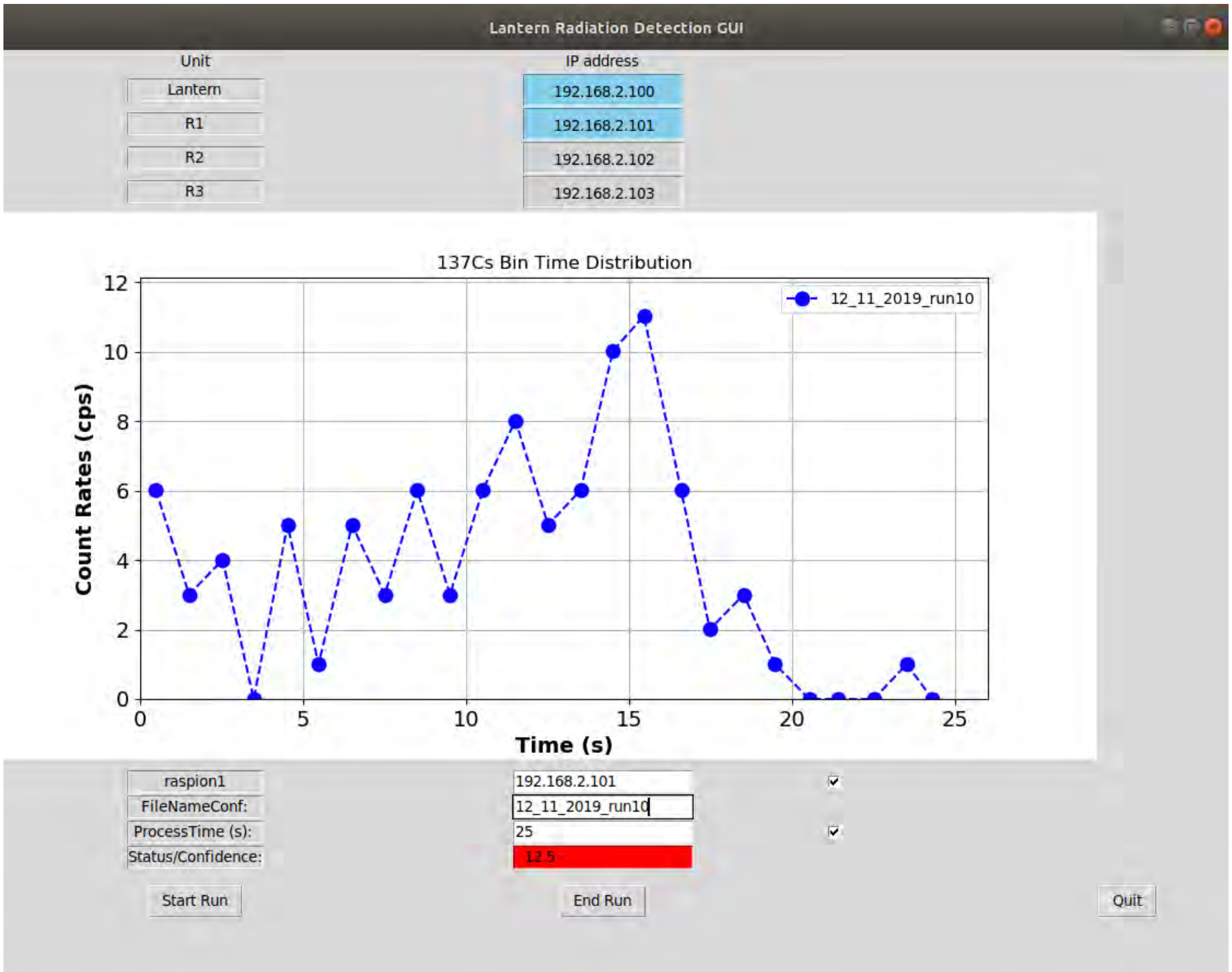


Figure 13: GUI Screen reflects source detection for the Run10 data

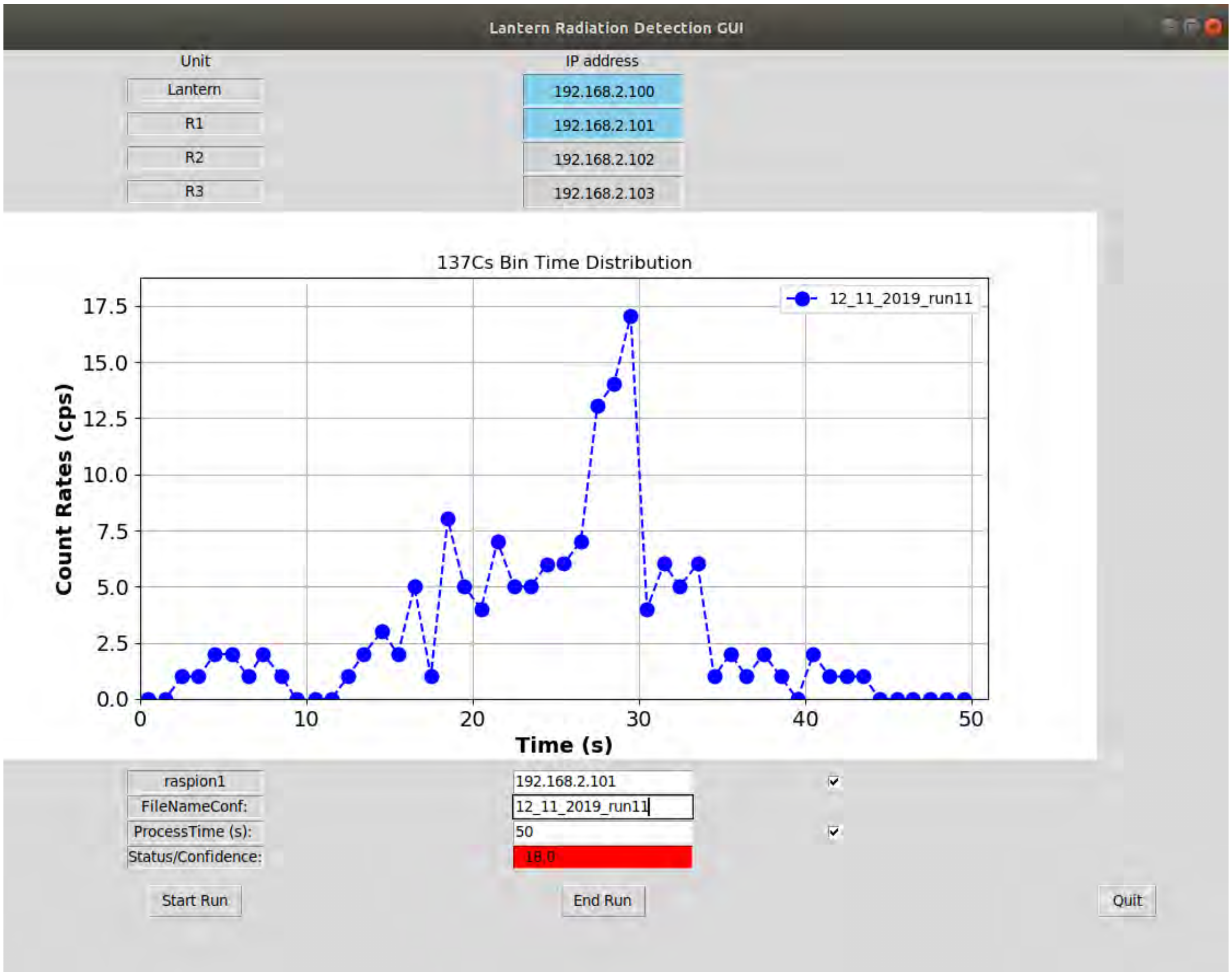


Figure 14: GUI Screen reflects source detection for the Run11 data

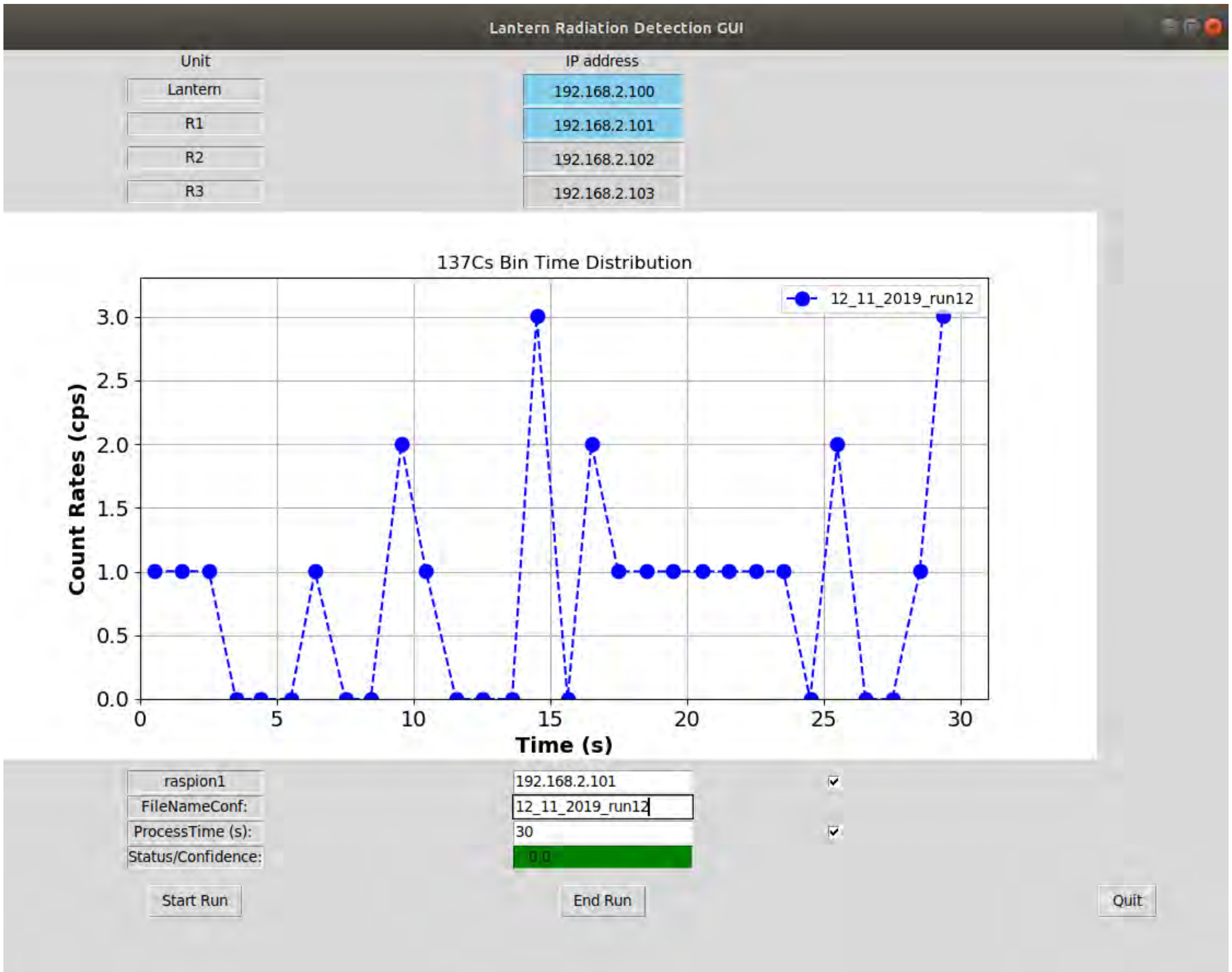


Figure 15: GUI Screen clears source detection for the Run12 data

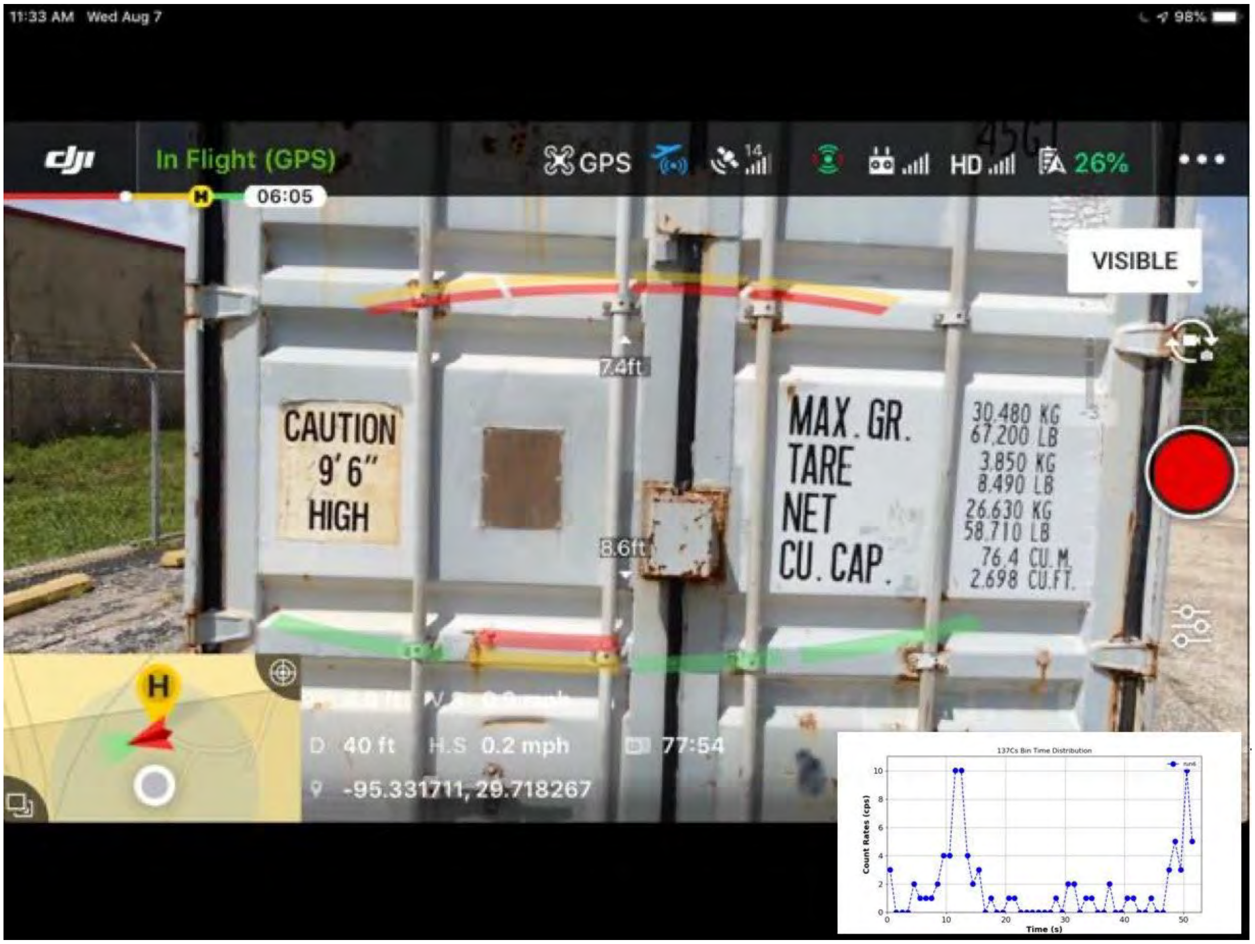
Implications of initial results

It needs to be emphasized that the 50µCi Cs137 is quite a small source, and the sources in many of the high priority situations for DHS operators, particularly a radiological dispersal device or "dirty bomb" would involve much stronger sources. The testing results indicate that the system is capable of detecting small radiation sources through container walls and vehicles at speeds that would be operationally reasonable in a port or stadium environment.

Integrating radiation detection into the drone's onboard controls

The December testing results established a foundation for us to now both detect and locate the sources in real time and integrate the source localization into the actual controls of the drone, instead of on a separate laptop. We have developed a custom simulation framework to test the signal localization capabilities of the system and to provide the basis for algorithm development. We ran one million simulations with random locations, varied drone speeds, and sources ranging from 50µCi to 300 50µCi. We compared the results predicted by the simulations against those obtained in our test flights, and they matched extremely closely. The results indicated that localization should be effective and gave us a clear path to effectively integrating localization into the system.

The next step was to develop an integrated system that will detect sources and show their location in real time to operators who do not have an expert physics background. We have now completed this, with the results displayed on the drone controls in real time. We have not been able to return to the test site for more flying since the application was completed, but the image below shows how the display will look on the screen of the drone operator. In the final few days of the grant period we worked to actually integrate the detector results into the camera feed, providing a 'heat map' that allows operators to see visual markers of radiation alerts overlayed into the images collected by the camera.



Meetings with CBP

Lantern UAS arranged meetings with the CBP OFO C-TPAT, NII, and CCS teams on Tuesday, February 18, 2020 to provide a briefing on the research. This included Jonathan Kolb and Eric Demarest from OFO/NII, Deputy Executive Director Dennis McKenzie from CCS, and Director Manny Garza from C-TPAT. Additionally, on Thursday, February 20, 2020 Houston Director of Field Operations Jud Murdock and Houston Seaport Port Director Roderick Hudson, along with a cargo security specialist, visited our test site at the University of Houston Technology Bridge. We were able to show them our existing radiation detection system, high resolution cameras, and thermal imaging with drones.

The CBP teams were very interested and provided a number of possible scenarios where this research could be of particular usefulness:

- They were very interested in the possibility of using drone-based thermal imaging to check freezer containers to identify narcotics smuggling, it is apparently common for criminals to remove the insulation in the container walls and replace it with narcotics, which should affect the heat signature.
- Checking non-refrigerated containers for unusual temperatures to identify possible storage of biological weapons, which would need to be kept at a stable temperature which could be reflected in the surface temperature of the containers.
- They were very interested in the possibility of testing neutron-detection on drone-based radiation detection systems.
- Using drone cameras to identify the presence of plant pests on hard to reach containers - by being able to capture images and indications of invasive insects on containers that may be high in the stacks drones could make agricultural inspections more efficient.
- Capturing images of seals on containers to check against manifests for containers that are not otherwise going to be searched.
- Using drones to check train cars in situations where stationary NII is not available.
- Using RFID devices on drones to identify containers and confirm the manifests.
- Incorporating drones in the break bulk area at the Port of Houston to scan cargo.
- Using drone-based radiation detection in situations, like at the Port of Philadelphia, where cargo moves through a populated area along a river channel before it arrives at the port and is scanned for radiation.
- Using drones to collect swipes from handles or vents of containers that can subsequently be analyzed in detail, especially when it would be dangerous for an officer to do so.
- Scanning float planes for radiation - this was a particular pain-point they mentioned, as when a float plane arrives across the northern border a pair of officers has to drive out, often several hours, to scan it by hand, and have trouble scanning the side facing the water. A system like ours could potentially make this a much simpler process.

Acknowledgment: This material is based upon work supported by the U.S. Department of Homeland Security under original Grant Award Number 2015-ST-061-BSH001-03.

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